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TITLE: STRUCTURAL-DESIGN CONSIDERATIONS FOR THE FED 50-kA EQUILIBRIUM FIELD COILS

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STRUCTURAL-DESIGN CONSIDERATIONS FOR THE FED 50-kA EQUILIBRIUM FIELD COILS

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ABSTRACT

The structural support system for two equilibrium field coil conductor concepts is considered for the fusion energy design (FED) 8/10T baseline magnetic fusion system. Both conductor concepts are discussed. Results indicate that regardless of the conductor concept employed, an external support beam/frame structural system is required to equilibrate the accumulative loadings.

INTRODUCTION

Structural support concepts for magnetic equilibrium field (EF) ring coils were studied with the goal of developing an economical and practical support system. We report the result based upon an analysis for the internally cooled cable superconductor (ICCS) of Ref. 1 versus an analysis for the pool bath cooled conductor (PBCC) described in Ref. 2.

Even though structural support systems for two competing coil designs were studied, the basic coil configuration with respect to the reactor is essentially the same. A schematic of the cross section showing the relative position of the coils is illustrated in Fig. 1. Our study concentrated on the EF2 coil of Fig. 1. Initially, the concept of a free-standing ring coil incorporating the structural support as an integral part of the ring coil was conceived. However, a free standing coil was considered to be impractical because the loading was not axisymmetric and large bending loads occur about both the radial and axial axis of the EF2 coil. Figure 2 represents an idealization of the loading that is produced by the interaction of the magnetic fields of the coils illustrated in Fig. 1. The loadings were approximated as sinusoidal with a period of 36 degrees. The maximum radial load was computed to be $6.70(10^6)$ N/m (38 260 lb/in.) while the maximum axial load was $4.14(10^6)$N/m (23 636 lb/in.). The design allowable stress for the structural support system assuming 316 LN stainless steel is 274 MPa (39 700 psi). This value is based upon a cyclic loading flaw propagation limit for 350 000 cycles at 10 T operation.

ICCS CONDUCTOR CONCEPT

The ICCS conductor configuration and basic dimensions are shown in Fig. 3. The structural support concept for this conductor is to transfer the magnetic structural loads through a load path of stacked channels to an external beam/frame supporting structure. The basic

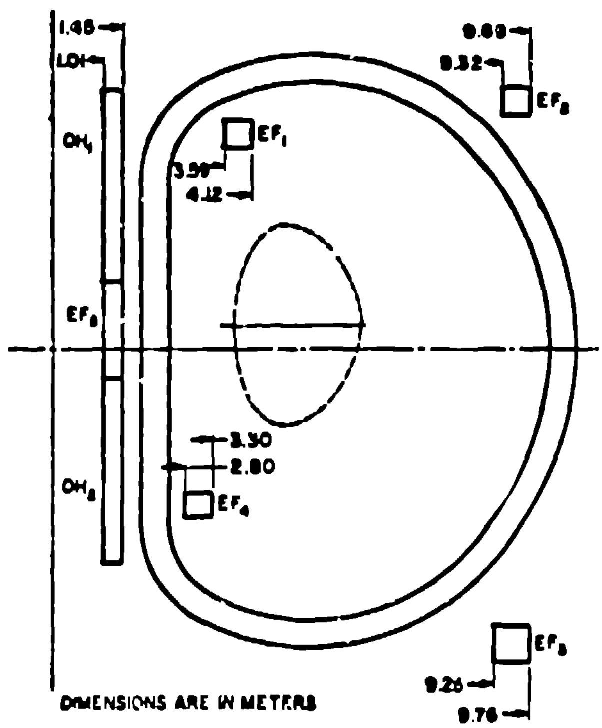

Fig. 1. Schematic of FED 8/10T magnetic system with ICCS coils.

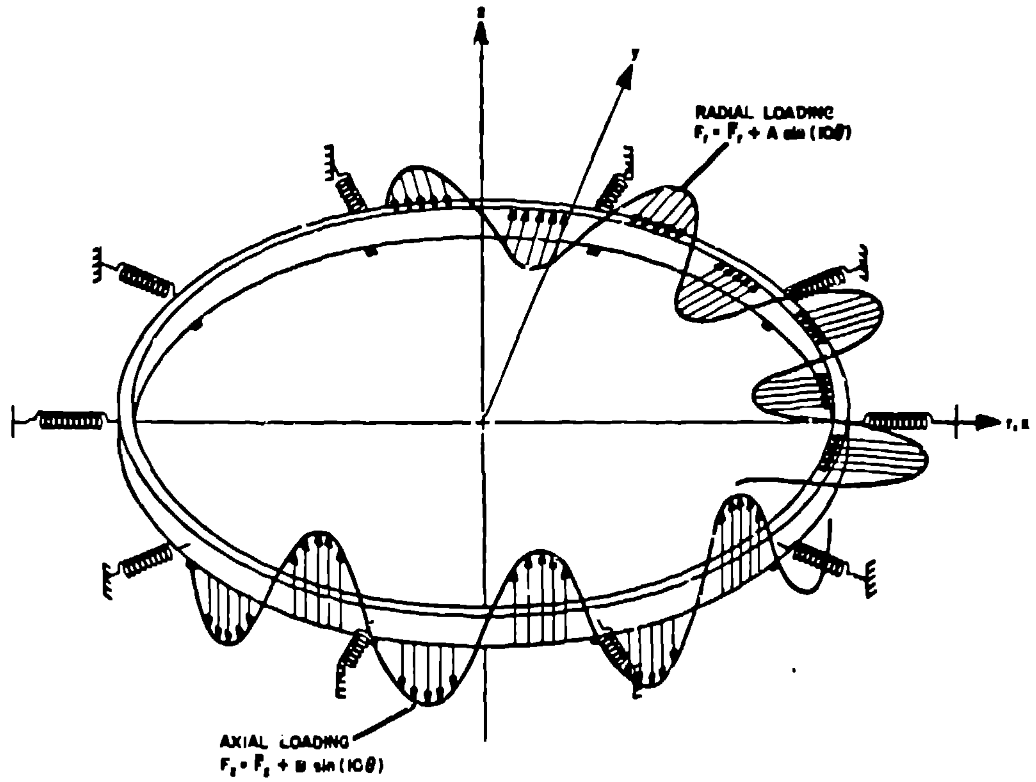

Fig. 2. Idealized EF2 ring coil illustrating support conditions and typical variation in radial and axial loading.

load transfer path is by membrane compression through the channel legs for radial loads and through channel webs for axial loadings. The channel sizes are governed by the bending stresses induced in either the channel webs or legs by the steel conduit enclosing the superconductor and bearing on the channel. Thus the channels are sized to transfer each conductor load into the overall load path. A 10 by 12 array of conductors is used for the EF2 coil. References 3 and 4 report sizing calculations for the ICCS conductor conduit and channels for all coils of the 8/10T fusion energy design (FED) concept.

PBBC CONDUCTOR CONCEPT

Two separate designs were proposed for the PBBC conductor and both were investigated.[5] The first design discussed is the self standing (no external structural support) concept. In this study an axisymmetric finite element structural model was used for preliminary

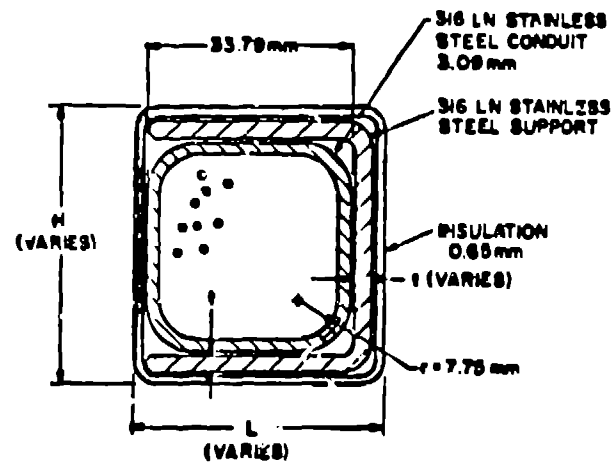

Fig. 3. ICCS conductor configuration showing basic dimensions.

analysis. The basic dimensions for the coil are shown in Fig. 4. In the concept analyzed here, the EF2 ring coil is built up using 31 co-wound layers of conductor and insulating material. A layer of steel was assumed to be co-wound with the conductor and insulating material. The minimum thickness of the steel layer was based upon the axial load that was transmitted through the coil structure. The EF2 coil is made of four co-wound coils and is referred to as a pancake structure. For the preliminary study only one pancake layer was modeled. The maximum radial load was distributed over the coil and a portion of the load was applied to each of the 31 conductors. The analysis was governed by the hoop stress and the only parameter that could significantly affect the hoop stress was the cross sectional area of the co-wound layers of steel. The area of steel was increased until each layer reached 2.5 cm in thickness and it was determined that ~ 2.5 cm (1 in.) layers of steel co-wound with the conductors would be necessary to reduce the hoop stress to an acceptable level. This amount of steel was considered excessive from the construction standpoint.

This design was modified by reducing the co-wound layers of steel to 1.27 mm, which is necessary to transmit axial loads from pancake coil to pancake coil, and assuming a band of steel that was to be positioned around the outside of the coil. It was found that a band of steel ~ 762 mm thick would be required to reduce the hoop stress to an acceptable value. Clearly an external supporting structure is preferable to a single band of steel of this size.

THE BEAM/FRAME SUPPORT SYSTEM FOR EF2

Regardless of whether the ICCS or PBBC conductor of the latter type is used, the most efficient method for handling the accumulative resultant loadings is to use an external beam/frame support structure.

The frame-type supporting structure of Fig. 5 was proposed by Hunter[3] and has been used as a guide for preliminary sizing of the structure proposed herein. A preliminary axisymmetric analysis led to an acceptable design solution, except that the actual loading for the coil varies sinusoidally in both the radial and axial directions. A more representative model was needed and a finite element model of the coil structural support was formulated using three-dimensional beam elements. A total of 360 elements was used to model the ring. The coil is supported by columns at ten locations evenly spaced around its circumference. There are ten toroidal field (TF) coils spaced evenly about the circumference of the ring that affect the loading for the EF2 coil. The coil can be idealized as shown in Fig. 2.

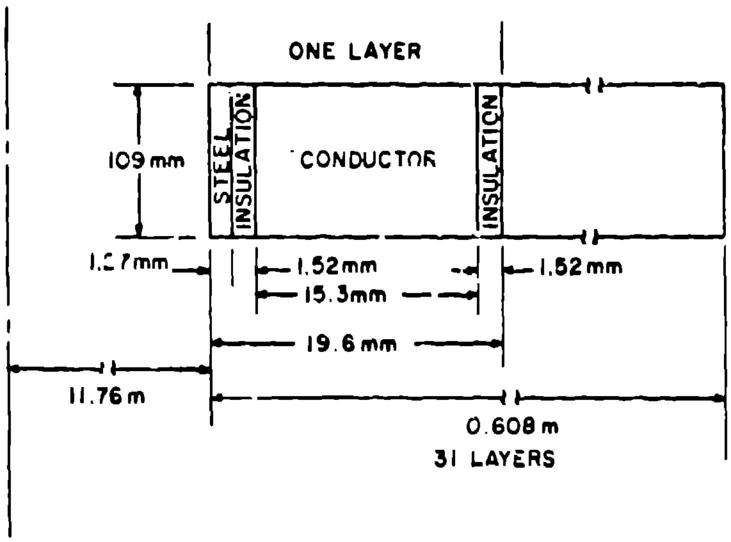

Fig. 4. Co-wound EF2 coil, one pancake layer (not to scale).

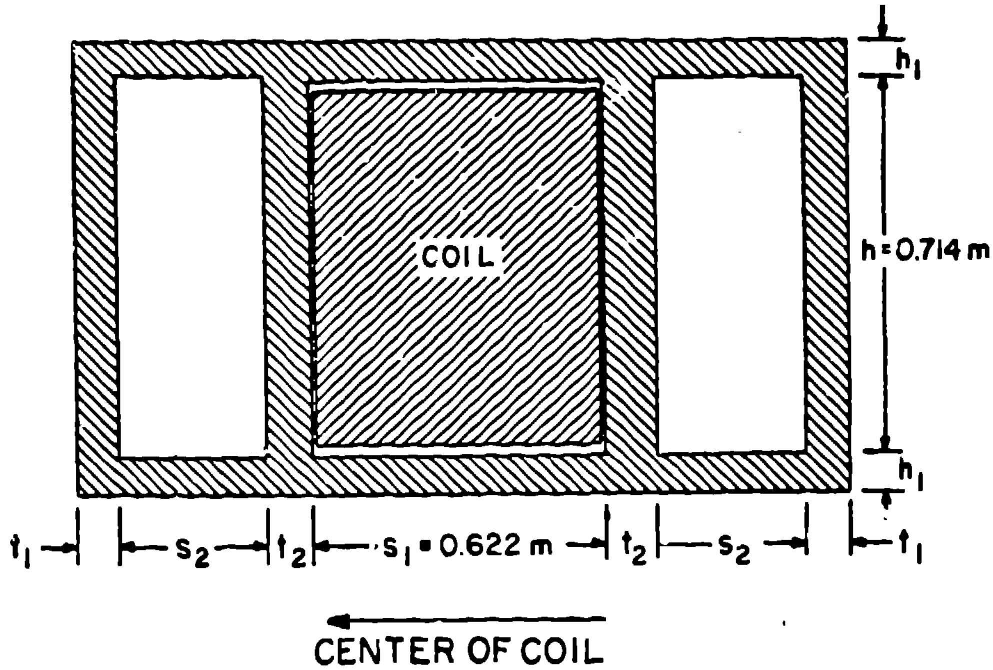

Fig. 5. Frame-type EF2 support structure (not to scale).

The ring and columns were assumed to be attached and an equivalent spring (truss) element was used at each support in the radial direction to simulate the stiffness of the column. The finite element analysis gave design parameters in terms of bending moments and beam axial force (hoop stress). The maximum moment caused by the radial loading was M_z = 5.70(10^6) N·m (50.5(10^6) in.·lb) and that caused by the axial loading was M_r = 5.81(10^6) N·m (51.4(10^6) in.·lb). The axial force for all frame type support configurations was approximately 34.20(10^6) N (7.69(10^6) lb).

CONCLUSION

1. The design of the structural support system for the equilibrium field coil, EF2, was attempted by analyzing different conceptual designs for conductor configuration and support. Design computations indicate that a frame-type structural support system regardless of conductor concept will be more suitable than a structural system of steel straps co-wound with the coil conductor.

2. A support system for the PBBC conductor described as self standing is impractical.

3. A preliminary axisymmetric analysis of either coil is feasible because of the economy in computation cost. However, the analyst must be aware of the unsymmetrical radial and axial loadings.

4. The minimum required area for the support system is dependent upon the hoop stress that remains constant for most cross section configurations. The resistance to bending loads is dependent upon the support configuration that gives maximum moment of inertia with respect to the r and z axis. However, the analyst must be aware of limitations imposed by physical space in the total reactor complex.

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